

Justification For Nuclear Structure Research

C.J. Lister

Nuclear astrophysics research is straightforward to rationalize as it applies knowledge of nuclear structure to star burning, nucleosynthesis, novae, and galactic evolution. Consequently, it fits nuclear structure into the “Big Picture” of understanding how the universe started and evolves to this day.

Fundamental interaction research is straightforward to rationalize as it applies knowledge of nuclear structure to understanding the forces and underlying symmetries of nature. Understanding the forces and symmetries leads to a more unified picture of nature.

So why is the abstract study of nuclear structure so difficult to justify? Many astrophysics and fundamental problems involve more precise understanding of nuclear wavefunctions.

Perhaps it is because there is a perception that we know nuclear structure as well as we can, as it is “too complicated”

Perhaps it is because there is a perception that we have been studying nuclear structure for 50 years, so we understand it well enough, and structure is now “calculable”.

Probably it is true that contemporary nuclear research has strayed far from any central theme, and its diversity has distracted from any clear perception of any central goal.

However, the central themes for nuclear structure are simple and are more clear at this moment than they have been for many years.

- A) Understanding the relationship between “bare” nuclear forces and the effective forces which are found in the nucleus.
- B) Understanding the relationship between the nuclear structure of stable nuclei and nuclei at the driplines, especially those nuclei with big neutron excesses.

Both A) and B) are closely tied to Astrophysics and studies of fundamental interactions, and are of considerable importance in themselves.

Both A) and B) have showed exciting promise for real advances in the near-term future and considerable progress can be expected.

Both A) and B) are linked: The theoretical advances in understanding effective nuclear interactions in light nuclei clearly indicate a strong influence of three-body forces which are density and isospin dependent, and so may be quite different from the effective interactions in the valley of stability. Conversely, the properties of many dripline nuclei show characteristics quite distinct from their more stable counterparts.

Investigating how the nuclear mean field and effective interactions change far from stability.

In heavy nuclei, say beyond $Z=20$, almost nothing is known about nuclei near the neutron dripline. However, it is in these nuclei that drastic modification of the nuclear meanfield must occur, as these nuclei are expected to be bound even when there are twice as many neutrons as protons, and the excess neutrons cannot be accommodated within the normal mean field. Either the proton and neutron fields remain homogeneous, greatly reducing the central proton density, or a skin or halo of neutron-rich matter must emerge. Here, in these neutron-rich nuclei, however, lie the sites where all heavy nuclei are synthesized, and where experimental access may be achieved with a RIA facility.

Experimental investigations of nuclear structure at RIA should focus on nuclei as far from the valley of stability as is possible with the aim of seeking modifications of the meanfield. The most important experiments are clear:

- 1) Locating single particle states and measuring the quantum numbers of states with the specific goals of measuring the strength of the spin-orbit splitting, and effective n-body residual interactions.
- 2) Measuring the collective response of the mean field, to deformations, vibrations and compression.

3) Measuring the difference in charge and matter distributions.

Fifty years of nuclear structure research has taught us some lessons. One is that most of these measurements can best (i.e. most precisely and unambiguously) be made in relatively low energy nuclear reactions, that is, quite near to the Coulomb barrier. The ONLY exceptions to this are studying Giant Resonance modes, where high energy probes are frequently essential. For single particle aspects, light ion induced reactions are far and away the best tools. With a RIA facility, this means reactions in “inverse kinematics” with the radioactive beams impinging on $^1,2,3\text{H}$, $^3,4\text{He}$ etc. targets. For studying low-lying collective aspects, like rotation and vibration, then classical sub-barrier Coulomb excitation is most unambiguous. Finally, the most clear-cut matter distribution measurements can be made through low-energy inelastic scattering.

For all the low energy studies, the optimum choice of beam in abstract, devoid of practical (or political) considerations, is a single pure beam (no isotopic or isobaric contamination) of well defined energy and low emittance.

Claims that fragmentation beams are better are NEVER true in the abstract sense, and only gain credibility as they are available. A great deal of obfuscation and making virtues out of necessity have clouded this issue.